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The Unique Cosmic Event of 1979 March 5

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Abstract

A spectacular transient that appears to be neither a typical gamma-ray burst nor an x-ray burster has been found to possess a variety of unusual properties that would seem to be mutually inconsistent. These observed parameters include a < 200 microsecond onset time, a subsequent temporal intensity oscillation with an 8-second period, a spectral feature consistent with a moderately red-shifted positron annihilation line, a maximum photon flux greater than any known gamma ray or x-ray transient, and a very accurate source location measurement consistent with that of the N49 supernova remnant associated with the Large Magellanic Cloud at 55 kpc distance. In addition, the ratio of x-ray point-source steady state to transient emission is $<10^{-9}$, independent of distance.

Given the accuracy of the observations (made possible by a gamma-ray burst network of nine spacecraft, complemented by data from five additional instruments), this phenomenon prompts both more theoretical examination of non-equilibrium high-energy processes and more experimental study, with greater spectral, temporal and directional resolution, devoted to transient gamma-ray phenomena in astrophysics.

Introduction

The experimental data regarding the 1979 March 5 transient can be reviewed briefly as follows. First, the time history is shown in its large-scale features in Figure 1, illustrating the relative intensity of the initial narrow maximum and the subsequent complex but regular oscillation. What is not evident on this time scale is the rise time of the intensity onset (< 200 microseconds and possibly

much shorter) and the width of the initial spike ($\sim$ 120 milliseconds). The observations plotted here were made with our Goddard instruments on the ISEE-3 spacecraft[1] and are confirmed in their general features with data from the other contributing sensors that form the interplanetary gamma-ray burst netowrk: Helios-2, Pioneer-Venus Orbiter, Venera-11 and -12, Prognoz-7 and the three Vela spacecraft[1,2,3], and by other instruments on Venera-11 and -12[4]. The gamma ray burst network is presently used to define gamma-ray transient source positions by triangulation over great distances, and performed the accurate and redundantly determined source location of this transient.[2] The maximum intensity is > several $\times 10^{-3}$ erg cm^{-2}sec^{-1}, an unsure and probably minimum value due both to the unknown fluxes below the $\geqslant$ 50 keV thresholds and to the problems of pulse pile-up effects at these energies. The intensity above about 100 keV is thus <u>at least</u> one order of magnitude greater than that of any gamma-ray burst observed during the ten years of essentially continuous monitoring with the Vela system[5]. The intensity of the oscillating decay phase decreases from $\sim 2\times 10^{-4}$ ergs cm^{-2}sec^{-1}, a more typical gamma-ray burst intensity, but exhibits a totally untypical phenomenon for bursts in its regular, periodic nature. The great intensity, fast rise time, narrow and featureless initial spike, and the regular > 22-interval 8-second oscillation with its compound pulse shape all argue against its classification as a typical gamma-ray burst[1].

The spectra of the two portions of this transient as measured with scintillator spectrometers on the Venera-11 and -12 space probes[4] are shown in Figure 2. These results are from independent experiments on the same spacecraft series involved in the burst network. The spectrum observed during the initial high-intensity portion generally conforms to a steep power law decreasing from its threshold of $\sim$ 30 keV, but with a distinct line feature at $\approx$ 400 to 430 keV. The average spectrum of the decay phase containing the oscillation is steeper and featureless. (This line appears to be statistically significant; its credibility circumstantially enhances and is enhanced by reports of similar $\approx$ 400-keV spectral

features that appear to be evident (i), in a long duration, 20-minute gamma-ray transient observed with balloon-borne instruments in 1974[6], (ii), in some, but not all, typical gamma-ray bursts[7,8], and (iii), in a May, 1976 balloon study of the general direction of the Crab Nebula which found a narrow line at this energy in one exposure but not in another[9], thereby at least consistent with a transient effect.)

The direction of the wavefront determined using the interplanetary spacecraft array forming the gamma ray burst network described earlier is localized to a region slightly larger than 1'x2', having its center about 40" from the center of N49[2]. An error box of this size is generally considered, when including a candidate source object of this obvious nature, to form an identification. In this case, the argument is clouded by the facts that typical gamma-ray bursts have not been found to have source directions consistent with objects of obvious candidate character[10,11] and that N49 is not at all an obvious source candidate, considering that its distance is 55 kpc.

Three additional small transients were observed with Venera-11 and -12 to follow the March 5 event by ≈ 0.6, 29 and 50 days delay, with intensities of ≈ 3, 1 and 0.5 percent that of the peak March 5 intensity, respectively[12]. A very rough inverse proportionality is evident in that the greater the relative delay from one event to the next the smaller the relative intensity. This is a distinctly different situation than that of the typical relaxation oscillator model of x-ray transients. The intensity profiles of these are generally wider than that of the initial March 5 spike, but, at up to 1 second wide, they are more similar to it than to typical, Vela-type gamma-ray bursts. The directions are coarsely resolved, due both to the low intensities and to the fact that these events were not detected by other sensors participating in the long-baseline gamma ray network; however, given their sequential and temporal connection to the March 5 event, and given that the initial March 6 event error box of several square

degrees is consistent with that for the March 5 event[4], the supposition of their common source seems assured. The intensities were too weak to obtain data above 10 keV; below that their spectra resemble that of the March 5 event[12].

X-ray measurements of the N49 region were carried out with the Einstein Observatory on occasions that happened to be a few days prior to and following the March 5 event[13]. No point source was found, although the investigators were able to set certain very strong limits: an upper limit to the change in flux is 2×10^{-12} erg $cm^{-2}sec^{-1}$, which is also the point-source flux upper limit. This is a more important result than that of a statement of nondetection of the neutron star implicit in a supernova remnant; it shows that the transient to steady-state x-ray ratio is $>10^{9}$, independent of distance. The authors conclude that, if N49 is regarded as a chance background object, a close-by galactic neutron star origin for the March 5 event is unlikely, since x-rays from interstellar accretion onto an isolated neutron star would require a steady state emission above the limits obtained scanning the source region[13].

Discussion

The unique temporal properties of this transient would be amply fascinating in themselves, even if it could be assumed to have originated in a nearby white dwarf or pulsar; the strong identification with N49 at 55 kpc is what creates an even more puzzling mystery. In our opinion, the likelihood that the identification is accidental is remote: give a source field of area about 2×10^{-8} that of the celestial sphere, depending on the proximity requirements for a SNR identification, the random probability varies from 10^{-6} to 10^{-4} for this to be a coincidence[2]. However, if known extragalactic objects <u>only</u> are selected for accidental identification, the probability of a chance coincidence is certainly much smaller. The well-known dangers of post-hoc statistical inferences should of course be kept in mind, but we feel that the association with N49 is real. Obviously, if the interplanetary burst network had not been in existence when this once-per-decade event occurred, a low-resolution, several square degree source field instead, typical of earlier burst localizations, would not

have provided the link to N49. Refinements in participating spacecraft temporal and spatial calibrations may in fact allow this error box to be shrunk by an order of magnitude in area. Such a result would be even more convincing if it localized a small region well inside N49; unfortunately, this is not available at the time of writing. A radio astronomy pulsar search would therefore be valuable at this time; also, a later optical study of N49, after several years, might even show some delayed effects of this outburst on the nebular structure.

The singular intensity of this transient seems inconsistent with an LMC source identification. Since it is more intense, by an order of magnitude than the most intense gamma-ray bursts, considerations of both the absolute and the relative intensity values are relevant. The absence of a continuously distributed size spectrum of smaller events is a problem: is this observation a statistical fluctuation, chancing on the occurrence of an effect that occurs not just once per decade but perhaps once per century? If the source is in the Large Magellanic Cloud and if galactic supernova remnants are similar in their characteristics to those in the LMC, then similar events should be evident from source objects inside this galaxy. These would have a greater frequency of occurrence and, typically, greater apparent magnitudes. Thus, the attendant size spectrum would predict a great number of events, perhaps $\geqslant 10^4$ per decade above the present thresholds for detectability.

A limit to this size spectrum is set by the Vela observations of only about 4 other gamma-ray bursts events of moderate intensity with ≈ 100 millisecond durations seen in the last ten years[14]. Also, balloon and satellite searches for less intense transient bursts fail to find either a continuing distribution of typical bursts at the lower flux levels[15,7] or a separate population of particularly brief, $\approx$ 100-msec events in any special abundance[16]. These several other narrow, $\approx$100-msec Vela events, due to their intensity, cannot be examined for post-onset oscillations of character similar to the March 5 event. Also,

their temporal resolution is limited to > 16 msec, and the celestial directions of these events are not well defined. Thus, we cannot conclude that smaller events like that of March 5 have never been observed, but only that their number is 4 or less per 10 years, at under one decade lower flux level. This result does not compare favorably with the expected size distribution and suggests that this is a particularly unusual event in any case.

The source output of the March 5 event would be as much as $\approx 5\times10^{44}$ ergs sec^{-1} if N49 radiated this outburst isotropically[2]. Typical, less intense gamma-ray bursts have been claimed to be restricted to origin distances of less than several hundred pc to several kpc, due to considerations of photon-photon scattering in the source region itself[17,18]. The March 5 event would therefore be even more inconsistent both with the equilibrium fireball model in the peak phase and with Eddington limited accretion in the pulsed phase. A recent treatment of photon-photon degradation in the March 5 event[19] estimates that the source distance is less than 200 pc unless beaming is present, in which case the limit is increased to over ≈4 kpc, and concludes that the N49 identification must be due to chance. It may be that very marked emission directivity could be present, accounting at least in part for the absence of a reasonable event size spectrum. However, very detailed and novel theoretical modeling will be necessary to find alternatives to these admittedly classical considerations.

The detection of the ≈ 420 keV line (unless that spectrum represents, instead, an equally curious absorption feature at ≈ 300 keV) clearly shows that annihilation photons do find their way of of the surface of a high photon density region that therefore cannot be given a purely classical, equilibrium photon-photon scattering treatment. The absence of this line feature in the oscillating decay phase may indicate the transition to a more easily explained situation. For example, a ≈ 20-to 30-keV temperature blackbody (not exactly matching the data but not too inconsistent with it) does fit the measurements for the observed flux

at the 55 kpc distance of N49 and a $\lessapprox 0.2$ light-millisecond, 60 km source size limit.

The 8-second period of the pulse structure is too slow to match the required pulsar fundamental spin period for N49, given its age at $\approx 1.5 \times 10^4$ years[22], but may yet be found to agree with the modeling of an excitation mode. All things considered, neutron star origin models for gamma ray transients are undeniably appealing, but to attribute the March 5 event to a nearby, invisible, neutron star is surely premature (given a possible local density of old neutron stars at 3×10^{-2} pc^{-3}, which does not violate the Oort limit[23], one such object could be contained within the conical error box volume 1000 pc in length[3]). This explanation may of course turn out to be entirely adequate to explain the traditional gamma ray bursts, which do appear to originate in empty source fields[10,11].

Finally, if the March 5 event did originate at the LMC, and if transients like it are in fact very rare occurrences per galaxy, depending on the galaxy, then a search for similar events from the nearest supercluster may yield a measurable event rate, given adequate detector sensitivity. The Gamma Ray Observatory is planned to include a large-area transient monitor; it turns out that this instrument will be capable of detecting such events from the Virgo region at a nearly daily rate, assuming a production rate of one per decade per galactic mass[24]. It is hoped that, in the next few years, equivalent progress will be made in the theoretical understanding of gamma-ray transients.

Table I

Observed Properties of 1979 March 5 Event

Initial Intensity Peak

Discernable by factor $>10^4$ above omnidirectional primary and secondary background

Onset time constant of less than 200 microseconds

Duration $\approx$120 milliseconds of initial, high intensity portion

Decay time constant $\approx$35 milliseconds, for $\geqslant$ 300 millisecond portion

Spectrum more intense <100 keV, rel. to >100 keV, than for typical gamma ray bursts

Spectral line feature at $\simeq$ 420 keV

Peak flux $\geq 2\times10^{-3}$ erg $cm^{-2}sec^{-1}$; > 10 x largest known gamma ray burst

Direction localized to $\approx$ 2'x1' region, with center $\sim$ 40" from center of N49

Flux equivalent to $\geqslant 5\times10^{44}$ erg sec^{-1} if omnidirectional from N49

Transient to steady state x-ray flux ratio $>10^9$, independent of source distance

Subsequent, Oscillating Intensity Decay

Oscillation period of 8.0 $\pm$0.05 seconds

Periodically repeating profile of compound, pulse/interpulse structure

Average decay time constant $\approx$ 50 seconds

Spectrally featureless and steeper >100 keV than for intensity peak

Flux of decay portion $\leq 2\times10^{-5}$ erg $cm^{-2}sec^{-1}$, $<10^{-2}$ that of peak

Total output equivalent $\geqslant 4\times10^{44}$ erg, if omnidirectional from N49

Delayed Bursts

Three weak events following initial event by $\approx$ 0.60, 29.37 and 50.11 days

Peak fluxes $\approx$3, 1, and 0.5 percent that of March 5 event, respectively

Intensity profiles roughly 1 second, 0.1 and 0.2 second FWHM, respectively

Direction of one event localized to $\approx 6^0\times0.4^0$ error box containing initial souce region

Spectrally similar to initial March 5 event <100 keV, not resolvable > 100 keV

Figure Captions

Figure 1. The intensity profile of the 1979 March 5 transient as observed with The GSFC/MPI instrumentation on the ISEE-3 spacecraft[1]. This event was also observed in varying detail by the solar orbiter Helios-2, the Pioneer-Venus Orbiter and the interplanetary Venera-11 and -12 spacecraft following their Venus encounters, and by at least six Earth-orbiting satellites. ISEE-3 used three independent sensors, and Venera-11 and -12, two each. The count rate is plotted as recorded for the first 8 seconds, and in 1/2-second time intervals for the next 48 seconds. Seven 8-second recurrent patterns are evident, shown delineated with dashed lines for clarity. A folding procedure was used to construct the remaining data presentation, in which groups of 8-second cycles are combined. The various features of pulse structure clearly remain in phase after more than twenty 8-second cycles, exhibiting a varying, complex pattern of one major and at least one minor peak per cycle. The initial <200-microsecond rise time, 120-msec wide counting rate peak is the most intense high-energy non-solar x-ray transient ever observed.

Figure 2. The energy spectra of (i), the intensity peak of the 1979 March 5 event[4], (ii) the average oscillating portion[4], (iii), the 1978 November 19 gamma-ray burst[8], and (iv), typical gamma ray bursts[20,21]. The existence of a feature at $\approx$ 420 keV in the 1979 March 5 event is consistent with the positron annihilation line, given the redshift appropriate for a neutron star. Strong suggestions of both this feature and another line at $\approx$700 keV are shown in a typical, Vela-type burst (iii) observed with the high-resolution ISEE-3 spectrometer[8]. The higher energy feature is consistent with the 847-keV firstexcited state of iron, given the same redshift. Observations of several similarly redshifted gamma ray lines

in a transient of much longer (20 minute) duration were obtained with a balloon-borne spectrometer[6]. Together, these measurements give strong circumstantial evidence that all three types of gamma-ray transients are consistent with neutron star origins. No gamma-ray transient has yet been observed to originate from a direction consistent with a known x-ray burster, however.

Figure 3. The source field error box for the 1979 March 5 transient as determined by the nine-spacecraft interplanetary gamma-ray burst network[2], plotted on the x-ray surface brightness contour map of the N49 and (N49) region, as observed with the HEAO-B high-resolution imager[11]. The contour levels correspond to 0.025, 0.1, 0.2, 0.4 and 0.62 counts $[(1'\times1')s]^{-1}$. No x-ray point source has been resolved. The change in x-ray intensity from shortly before to several days after March 5 event was $\leqslant 2\times10^{-12}$ erg cm^{-2}sec^{-1}, and the point source upper limit is also $\sim 2\times10^{-12}$ erg cm^{-2}sec^{-1}, or $\approx 10^{-9}$ that of the transient itself, independent of distance: The implied luminosity at 55 kpc is $<4\times10^{35}$ erg sec^{-1}, two orders of magnitude below that of a typical pulsating binary x-ray source, and at nearby interstellar distances may be inconsistent with accretion onto an isolated neutron star[11]. Thus, although classical photon density arguments are incompatible with a source at 55 kpc[17,18,19], a source at the distances preferred may have a steady-state x-ray emission problem.

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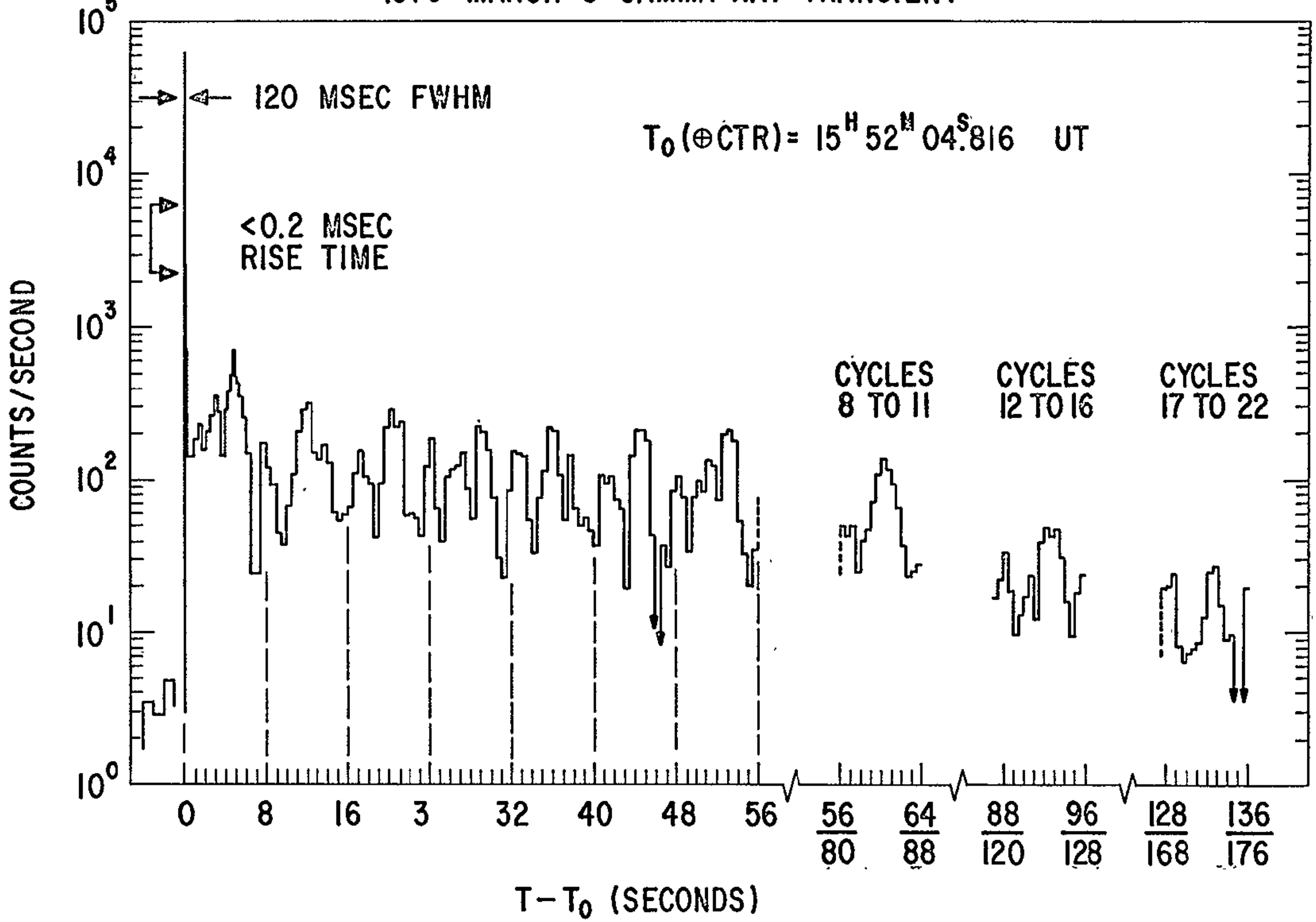
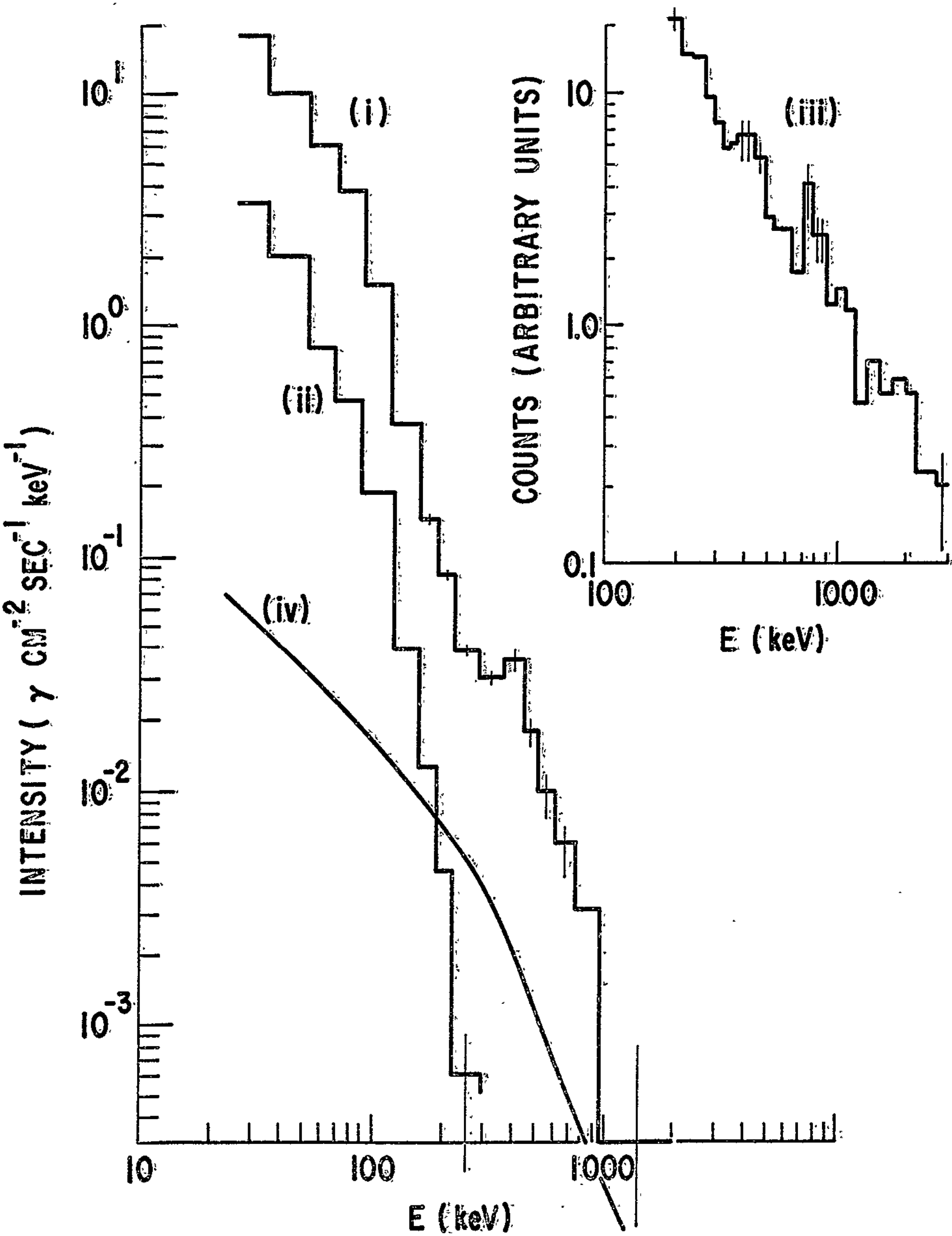
1979 MARCH 5 GAMMA RAY TRANSIENT





INTENSITY (γ CM⁻² SEC⁻¹ keV⁻¹)
10¹
10⁰
10⁻¹
10⁻²
10⁻³
(i)
(ii)
(iv)
10
100
1000
E (keV)
COUNTS (ARBITRARY UNITS)
(iii)
10
1.0
0.1
100
1000
E (keV)

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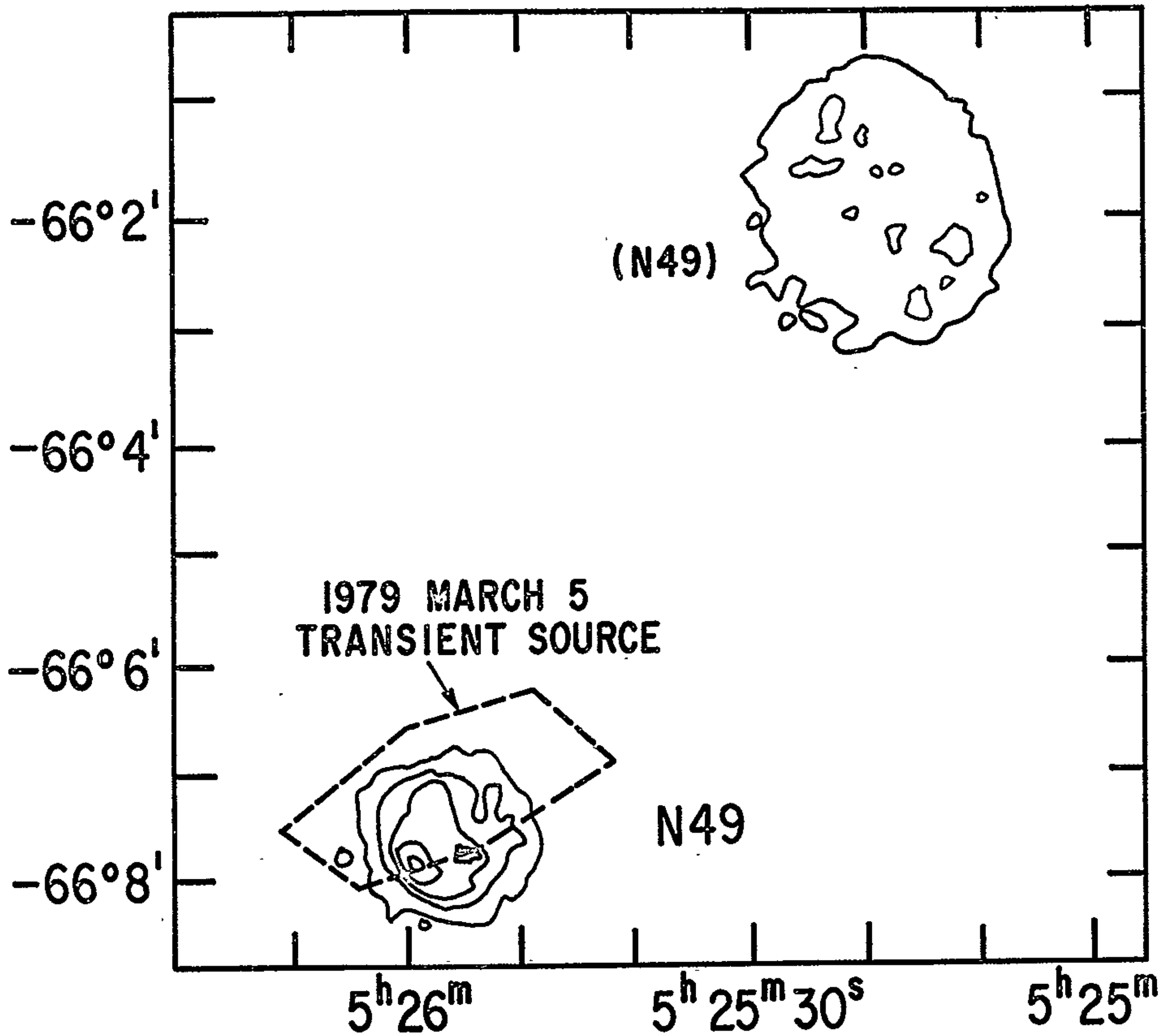

-66°2'
-66°4'
-66°6'
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(N49)
1979 MARCH 5
TRANSIENT SOURCE
N49
5h26m
5h25m30s
5h25m